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Indium-mercury Alloy as a Low-toxicity Liquid Electrode

In a number of electronic manufacturing and testing applications, such as the testing of terminal-to-case resistance in microelectronic components, the use of a conducting liquid as an electrode in room-temperature applications offers several advantages over other methods of making electrical contact. Solid electrodes, including matrices of point contacts and area-contact materials such as metal foil or metal shot, are quite limited in their ability to conform to the surfaces of very small components, and a metal such as mercury that is liquid at room temperature is an obviously preferable choice. Liquid mercury exhibits high electrical conductivity, a high surface tension (which prevents wetting of component surfaces), and chemical stability; it is unreactive with the epoxies, phenolic plastics and other materials commonly found in electronic devices and requires a minimum of recurring set-up time in a test environment. In pure form, however, mercury does have an appreciable vapor pressure and its vapor is quite toxic; concentrations in air of 0.1 mg/m^3 are immediately poisonous and concentrations as small as 0.001 mg/m^3 are dangerous under conditions of prolonged exposure.[1] Liquid alloys of mercury usually have an appreciably lower vapor pressure, but the choice of alloying metal must be made with care in order to avoid compromising the more desirable properties of the mercury. Gallium, for example, is very reactive and corrosive to most metals[2] and thallium, while very soluble in mercury, is corrosive, very toxic, and tends to wet surfaces.

Of the materials tested, indium metal was found to exhibit the most desirable properties. (Other metals were tested but did not exhibit the properties of indium; e.g., Zn was used but required several days to dissolve and effected no decrease in vapor pressure.) Indium is readily soluble in mercury, forming liquid alloys at room temperature in concentrations of up to 55 percent by weight.[3–6] It is oxidation resistant,[2] less reactive than gallium, and has no known toxic qualities.[7] Resistivity data[8] (shown in Table 1) indicate a conductivity of the order of 10^3 $(\text{ohm-cm})^{-1}$, and the metal is unreactive with epoxies and phenolics. Its effects on the toxicity and surface tension of mercury have been determined by experiment.

Table 1 Resistivity of liquid In-Hg alloys.[a]

Wt % In	*Resistivity*[b], *ohm-cm* $\times 10^{-6}$ *(approximate)*
0	93
5	90
10	82
20	79
30	75
40	75
50	72

[a] Ref. 8.
[b] At 1 atmosphere and 20°C.

Alloys of In-Hg were prepared by dissolving weighed quantities of high-purity In* into triply-distilled Hg. A vapor meter† was used to monitor the vapor emitted from a 10.4-in^2 surface by alloys of varying proportions by weight. (The instrument recorded concentration of Hg in air in mg/m^3; the median of the readings during a two-minute exposure was at least 10%, and in most cases 50%, lower than the maximum recorded concentration.) Surface tension of the alloy was determined by observing the meniscus on a borosilicate glass and by empirical measurement with an Instron Universal Tester, based on the surface tension of pure Hg[1] of 487 dyne-cm^{-1}.

Figure 1 is a plot of vapor concentration of Hg in air vs. percent by weight of In; all of the data points fall below the toxicity threshold (0.1 mg/m^3) except the point for pure Hg. All are higher, however, than the recommended limit for long-term exposure. The minimum in the curve was unexpected and has not been accounted for, although it occurred consistently in the experiments.

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* Supplied by Indium Corporation of America.
† Model K3, Beckman Instruments Corp.

A surface "skin" does form on the alloy when it is exposed to air, and this adheres weakly to some of the materials it would be expected to contact if used as an electrode. It does not wet these materials, however, and is readily removed by HCl vapor. Observations of the meniscus on glass indicated a surface tension of more than 154 dyne-cm^{-1}; direct results from the Instron Tester were inconclusive because the duNouy ring of the tester broke the surface unevenly. However, it was possible to calculate the tension by comparing the tensile force required to pull the ring through the surface of pure Hg with the force required for the alloy. These results are given in Table 2.

From Fig. 1 it can be concluded that toxicity at 25°C can be substantially reduced by using In-Hg alloys instead of pure Hg in the electrode bath. Quite probably the vapor pressure would increase with temperature, but it almost certainly would not exceed the toxicity threshold at room temperatures normally found in a laboratory or test facility. The long-term toxicity is still a potential problem, and the alloy does exhibit "hot spots" during electrical charging that can produce mercury vapor. With suitable safety precautions, however, there is low risk to the user.

The conductivity of the material is high (Table 1); its surface tension is adequate to prevent wetting (Table 2), and it is stable with time (samples of the alloy containing various proportions of In have been kept in the authors' laboratory for a year without degradation). Figure 1 indicates that, for use as a liquid electrode, the 2% alloy is to be recommended.

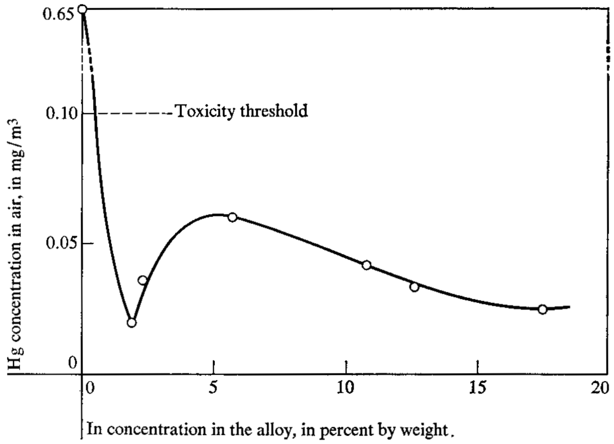

Figure 1 Mercury vapor concentration in air vs. concentration by weight of indium in the alloy. Temperature 25°C; exposure interval 2 minutes; each data point is the maximum value over the exposure interval.

Table 2 Surface tension data.

Wt % In	*Tensile load, lb.*	*Calculated surface tension, dyne-cm^{-1}*
0	3.35	487
2.3	1.28	186
10.8	1.79	260
17.8	2.08	302

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